SMA Science Highlights

- Solar system objects
- Protoplanetary disks
- Star formation
- Polarization and Magnetic fields
- Evolved star envelope
- Galactic Center/AGN
- Time domain astronomy
- Nearby and distant galaxies

- Remarks

Qizhou Zhang

Input from Sean Andrews, Shane Bussmann
Mark Gurwell, Jim Moran, Nimesh Patel, and David Wilner

Outline

- Solar system objects
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2007: Remnant Stratospheric HCN on Jupiter from Comet P/Shoemaker-Levy 9

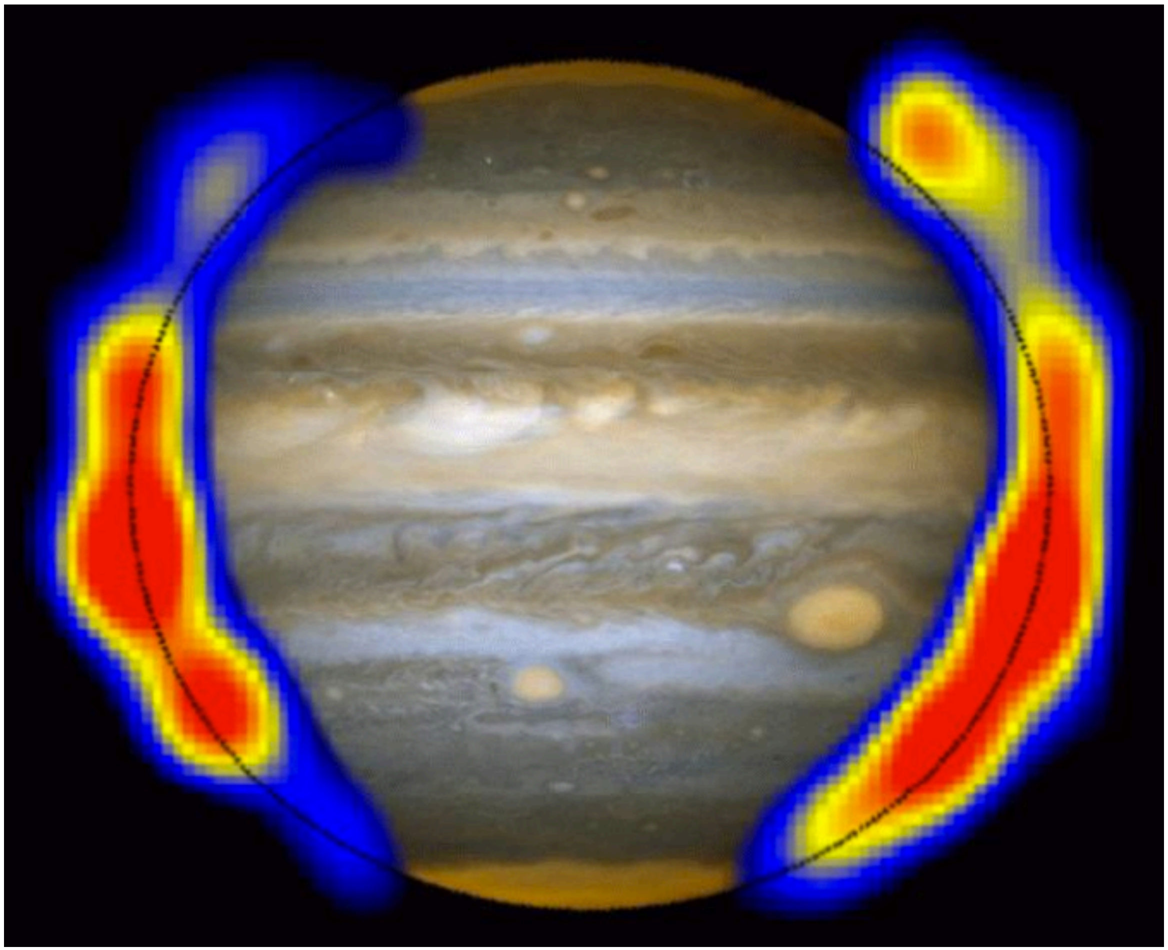


Image by Mark Gurwell

HCN, CO, and CS were seen in Jupiter's stratosphere only after the impacts of Comet P/Shoemaker-Levy 9 in July 1994. Since then, their abundances have decreased faster than expected. SMA imaging of Jupiter in April 2007 at 265.9 GHz show HCN(3-2) emission on the limbs (where path lengths are maximized). HCN is not seen at polar latitudes, suggesting that as it diffuses poleward, it is entrained in polar vortices and transported to lower altitudes where it is destroyed (Moreno et al 2007)

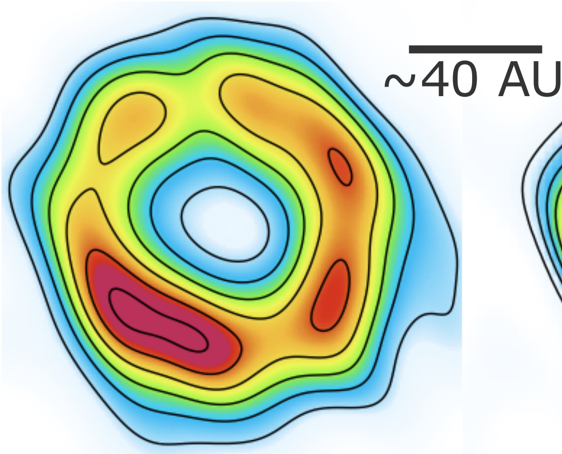
0.8mm Dust Emission of Planet Forming Disks

SMA imaging reveals detailed
structure of gas/dust in disks
around nearby young stars

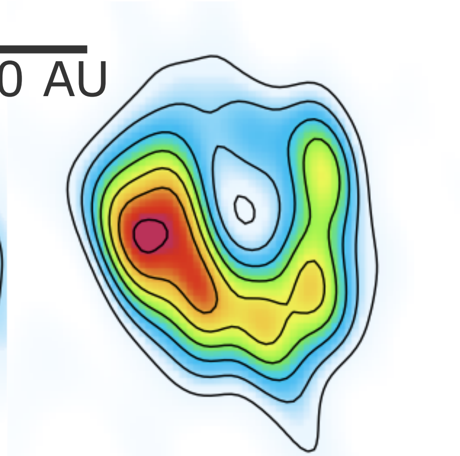
evidence for *planet formation in action*

many (most?) massive disks
have dust-depleted cavities
with radii of ~20-70 AU

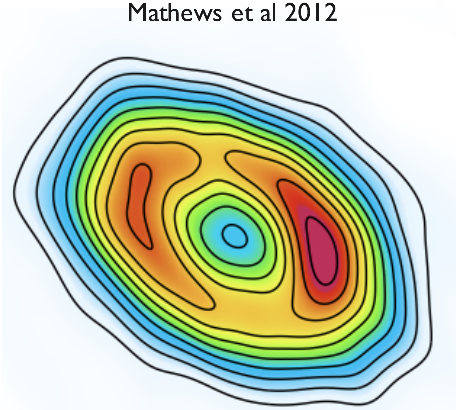
cleared by tidal interactions with
young (1 Myr) planetary systems



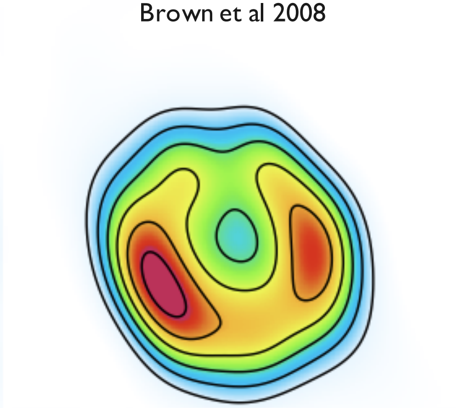
Mathews et al 2012



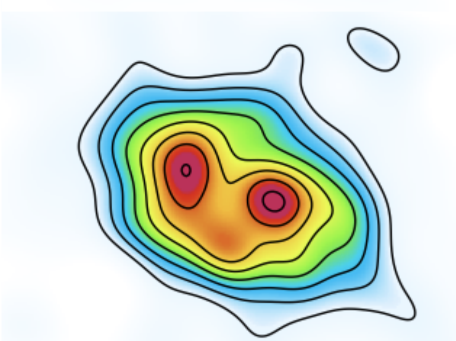
Brown et al 2008



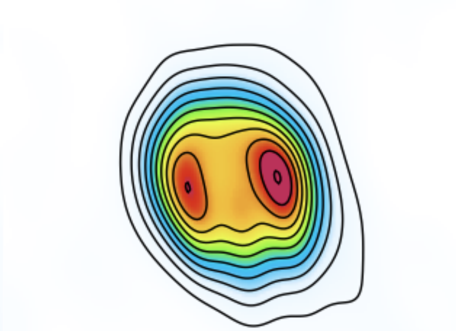
Andrews et al 2011



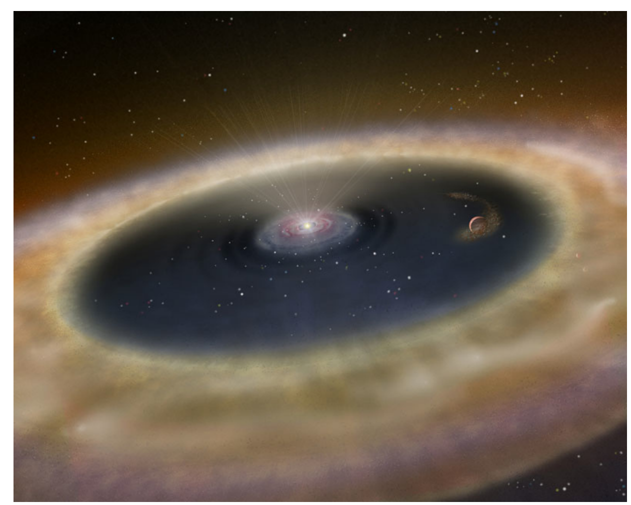
Andrews et al 2009



Hughes et al 2009



Rosenfeld et al 2012

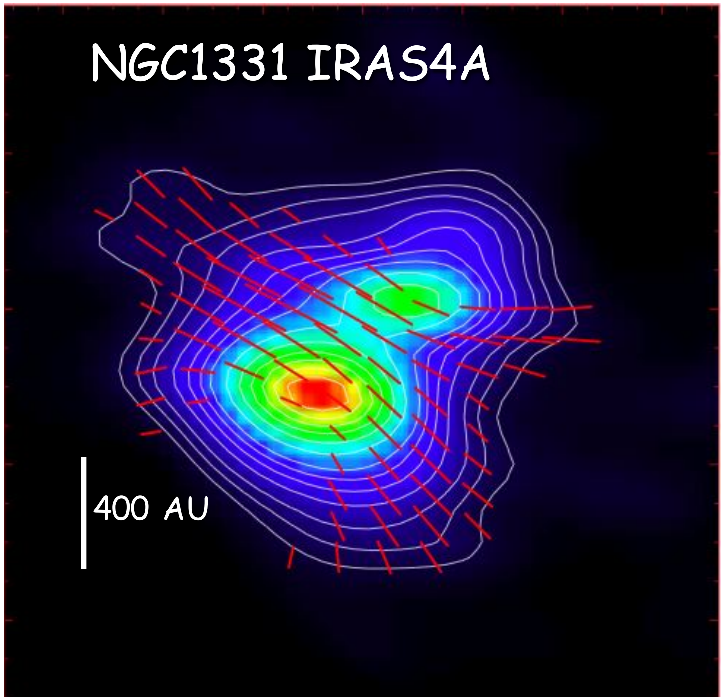


Kraus et al 2012; illustration by K Teramura

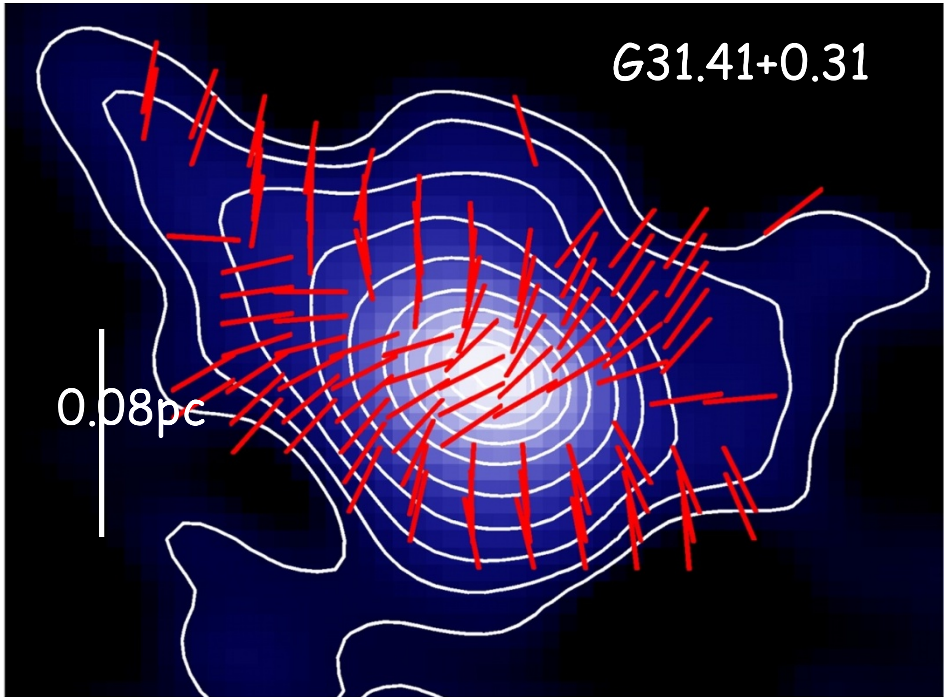
Polarized Dust Emission

Red bars -- magnetic field direction. Contours: 0.8mm dust continuum

Both objects show ordered magnetic field and a pinched hour glass morphology, indicating an important role of magnetic field in star formation



Girart, Rao & Marrone 2006



Girart, Beltran, Zhang, Rao, Estalella 2009

SMA Polarization Legacy Survey

Collaborative effort between SAO/ASIAA

21 massive molecular clumps, largest by (sub)mm interferometer

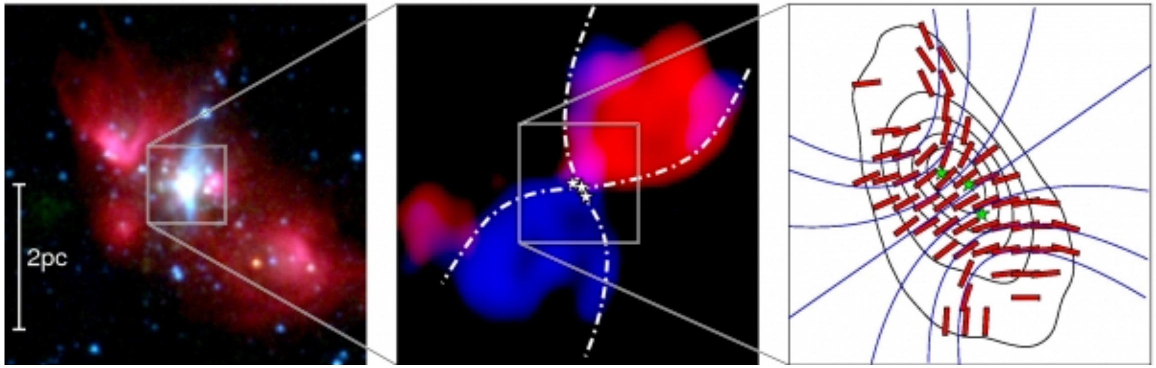
25 nights from 2011-2013 (enabled by x2 bandwidth c.a. 2009)

PI: Qizhou Zhang Co-Is: Keping Qiu, Ya-Wen Tang, Hau-Yu Liu, How-Huan Chen, Josep Girart, Ramprasad Rao, Paul Ho, Patrick Koch, Shih-Ping Lai, Hue-Ru Chen, Eric Keto, Zhi-Yun Li, Tao-Chung Ching, Sylvain Bontemps, Timea Csengeri, Huabai Li, Pau Frau, Marco Padovani

Publications:

- Girart, J. M., Frau, P., Zhang, Q., et al. 2013, ApJ, 772, 69
- Koch, P. M., Tang, Y.-W., Ho, P. T. P., et al. 2014, ApJ, 797, 99
- Li, H. et al. 2015, Nature, 520, 518
- Liu, H. B., Qiu, K., Zhang, Q., Girart, J. M., & Ho, P. T. P. 2013, ApJ, 771, 71
- Qiu, K., Zhang, Q., Menten, K. M., Liu, H. B., & Tang, Y.-W. 2013, ApJ, 779, 182
- Qiu, K., Zhang, Q., Menten, K. M., et al. 2014, ApJ, 794, L18
- Zhang, Q., Qiu, K., Girart, J. M., et al. 2014, ApJ, 792, 116

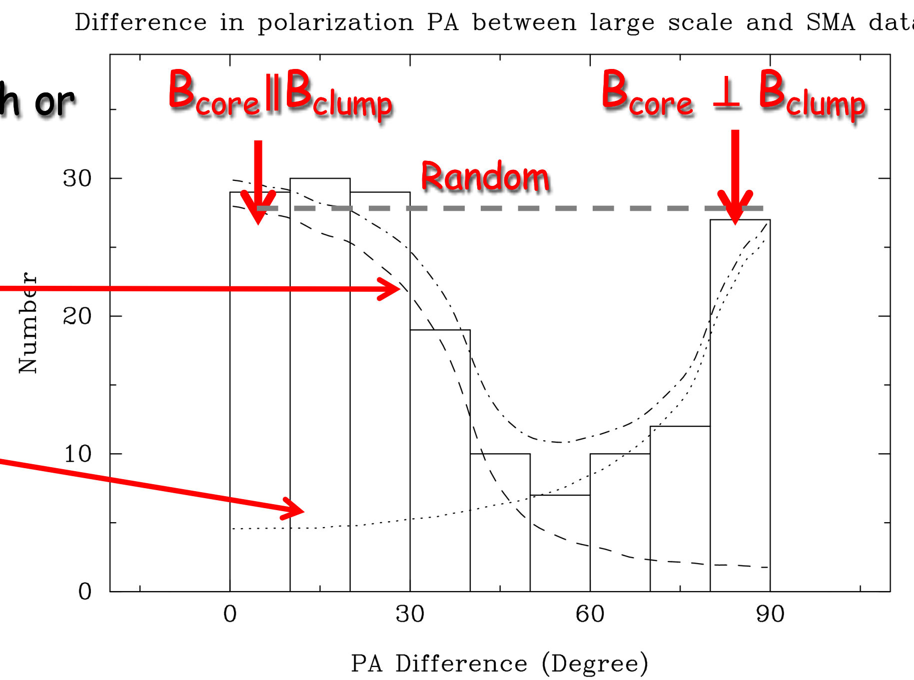
Magnetic Fields and Star Formation



Magnetic fields in dense cores align with or orthogonal to B in parental clump

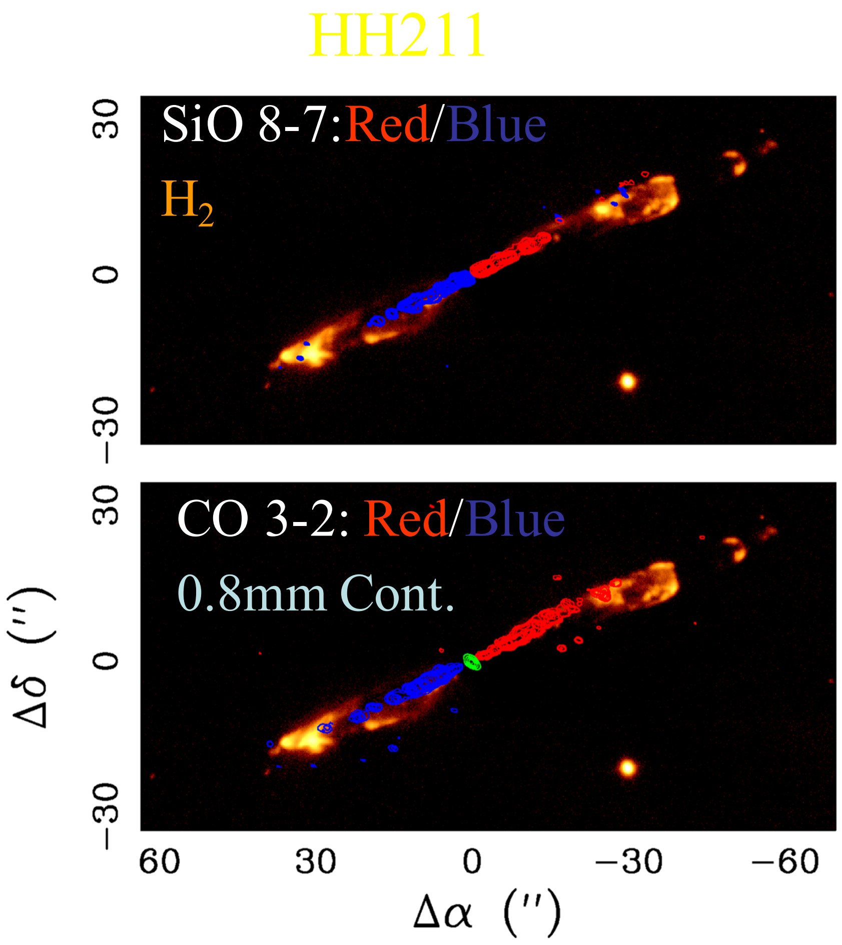
Simulation: B-fields aligned within a 35° cone

Simulation: B-fields aligned within a 80-90°



Qiu et al. 2014; Zhang et al. 2014

Jets from Youngest Class 0 Protostars

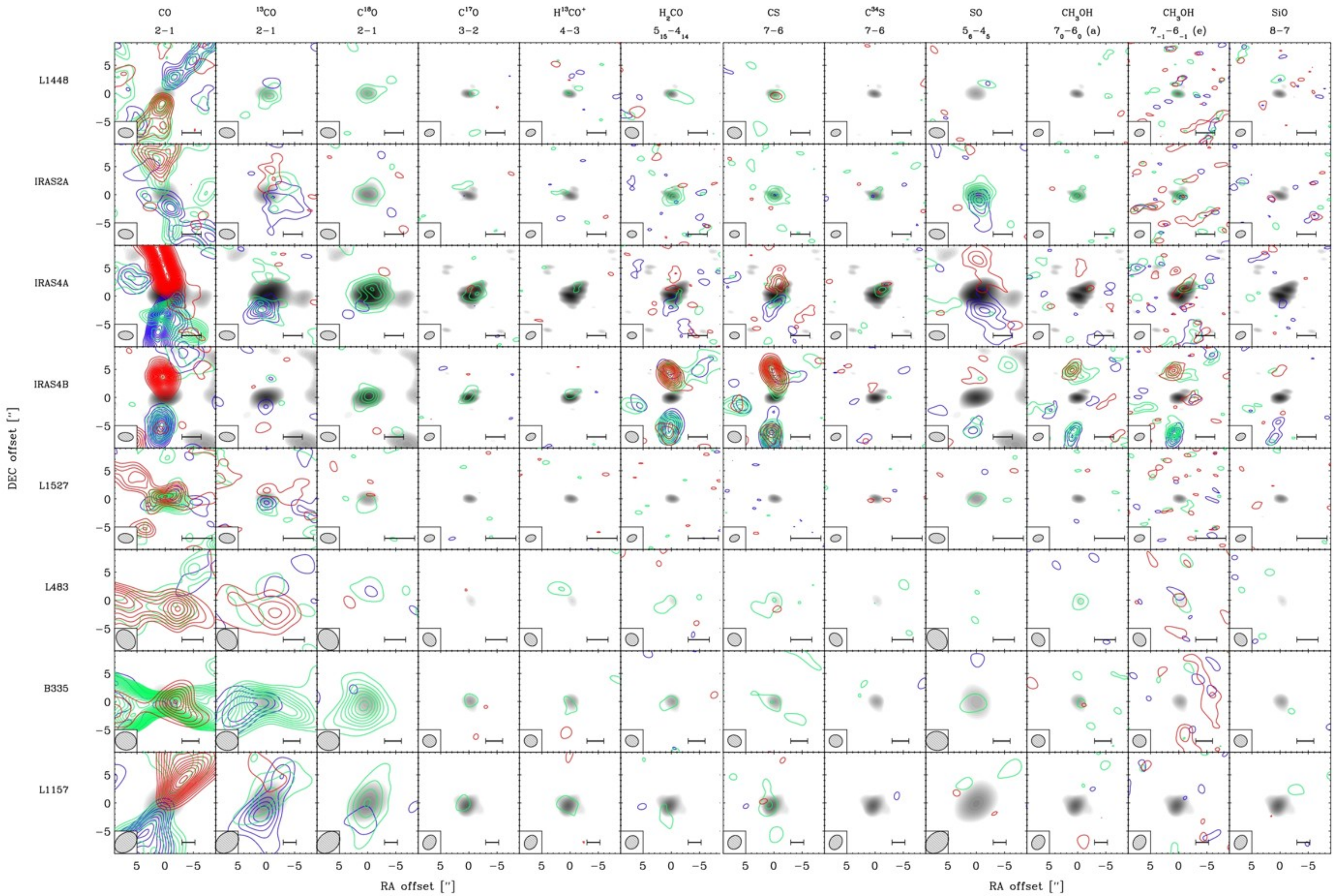


HH211: **Higher excitation gas in SiO 8-7 and CO 3-2 closer to central ctar and jet axis, and trace a high density (n_{H2} ~10^6 cm^{-3}) primary jet.**

Palau et al. 2005; Hirano et al. 2005; Lee et al. 2007

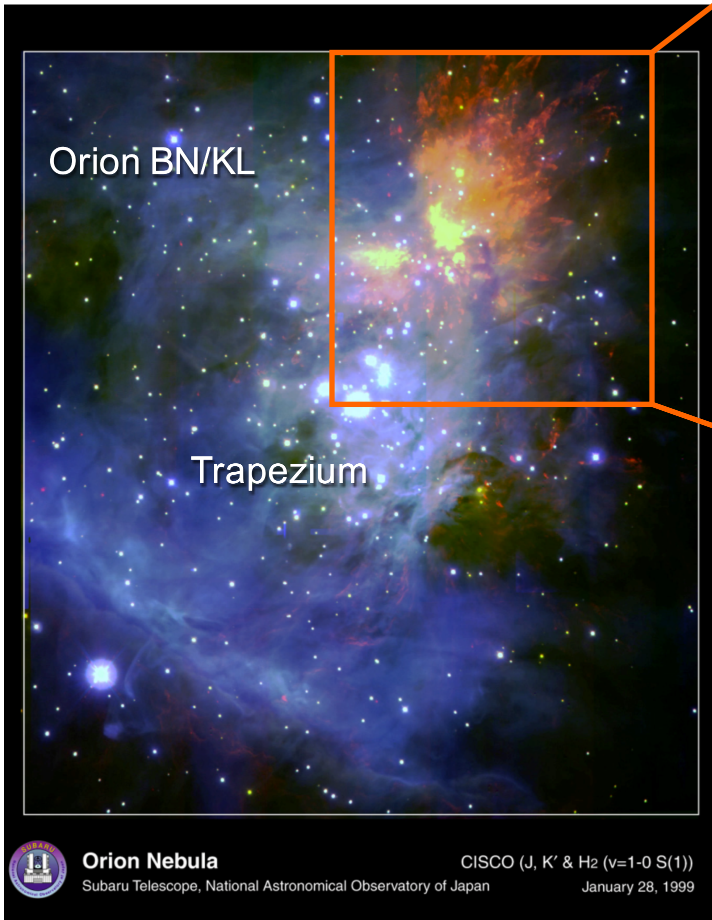
Protostellar Submillimeter Array Campaign (PROSAC)

Survey 9 Class 0 protostars in many lines and continuum (230/345 GHz)

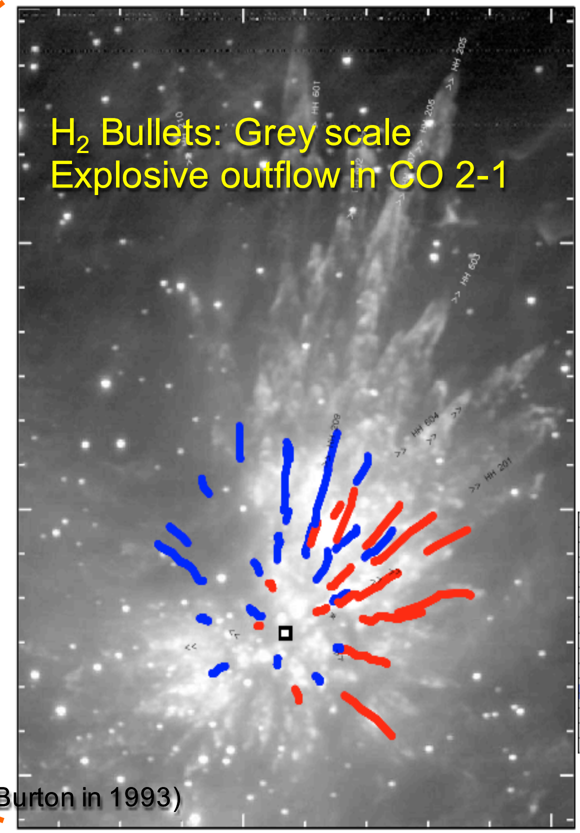


Jørgensen et al. 2007 ApJ, 659, 479 (Basic Results)

Dynamical interactions



Zapata et al 2009

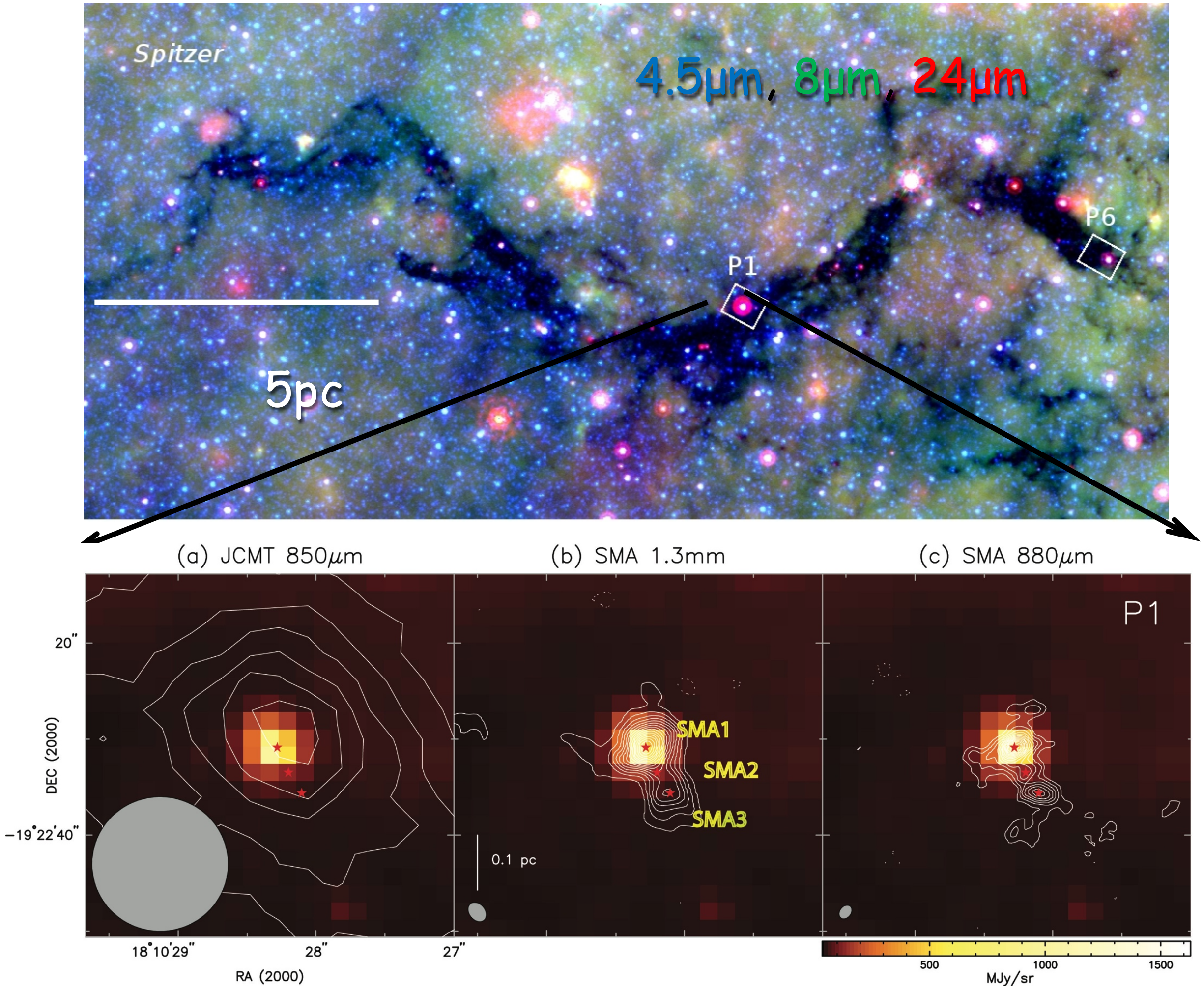


(Discovered by Allen & Burton in 1993)

L_{bol} ~10^5 L_{sun} (Orion BN/KL)
M ~ 10 M_{sun}
E ~ 10^{47} Erg
High vel. >100 km s^{-1}
Very poor collimated (degree of collimation 200° – 300°)
Bright in optical and infrared bands

Proper motion of three massive stars at center of outflow suggest common spatial location ~500 years ago

Infrared Dark Cloud G11.11: Fragmentation



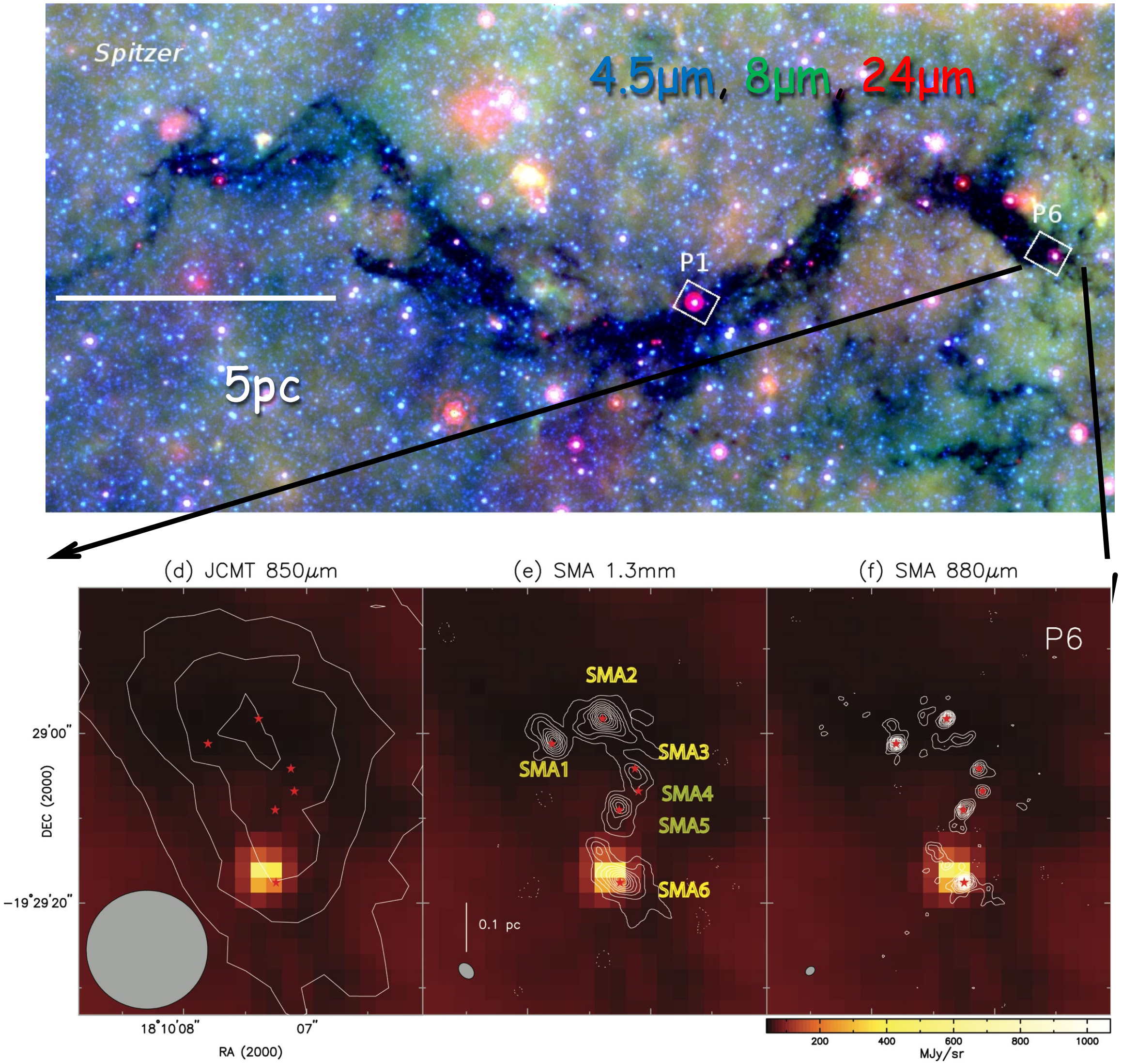
P1:
M(clump) ~ 10^3 Msun
L = 1300 Lsun
SMA detects 6 cores
5-23 Msun

P6:
M(clump) ~ 10^3 Msun
L = 140 Lsun
SMA detects 17 cores
3-28 Msun

T = 11-20 K
V = 1.5 kms^{-1}
M_{Jeans}(thermal) = 1 Msun
M_{vir} < M(cores)

Wang et al. 2014

Infrared Dark Cloud G11.11: Fragmentation



P1:
M(clump) ~ 10^3 Msun
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SMA detects 17 cores
3-28 Msun

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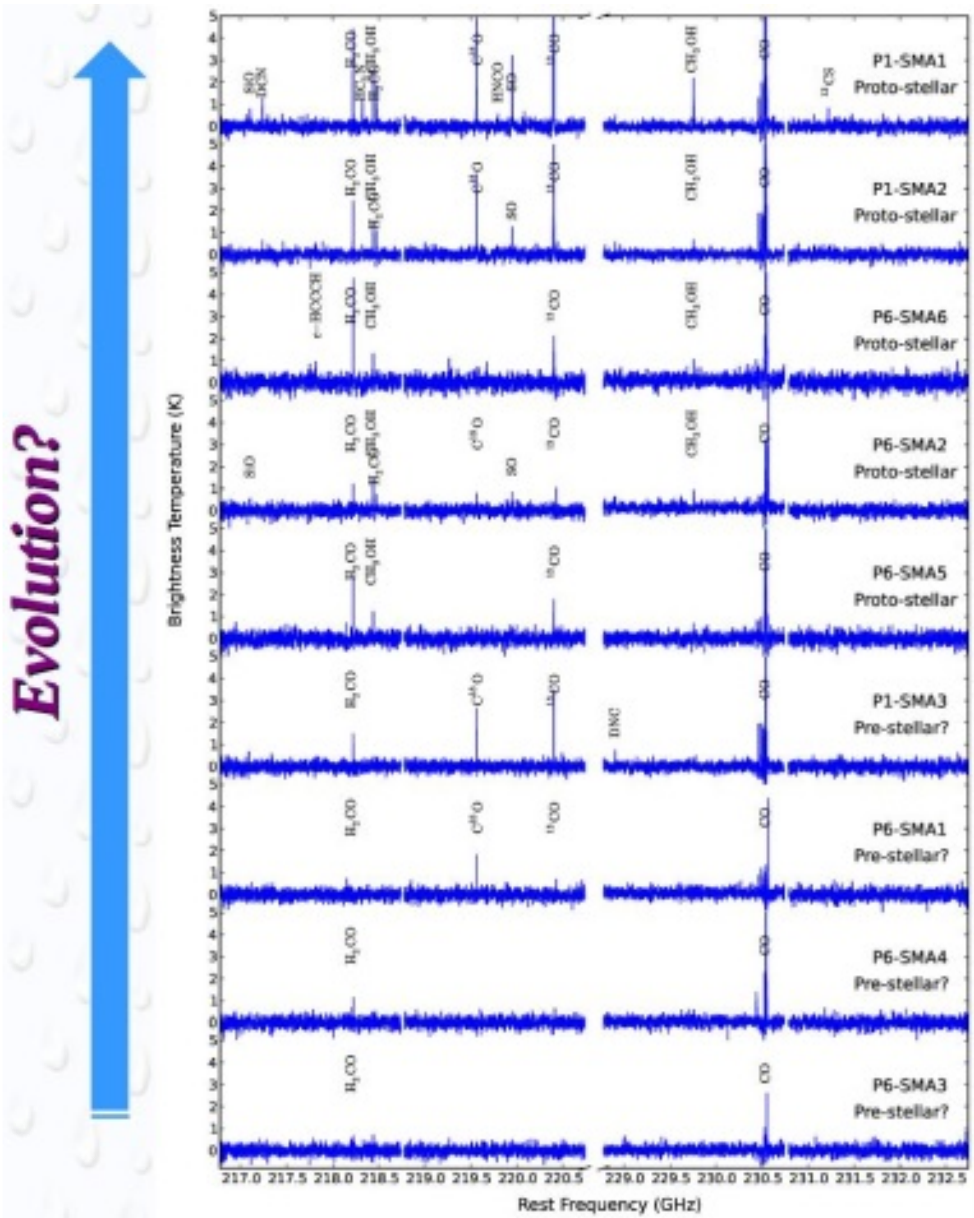
M_{vir} < M(cores)

Wang et al. 2014

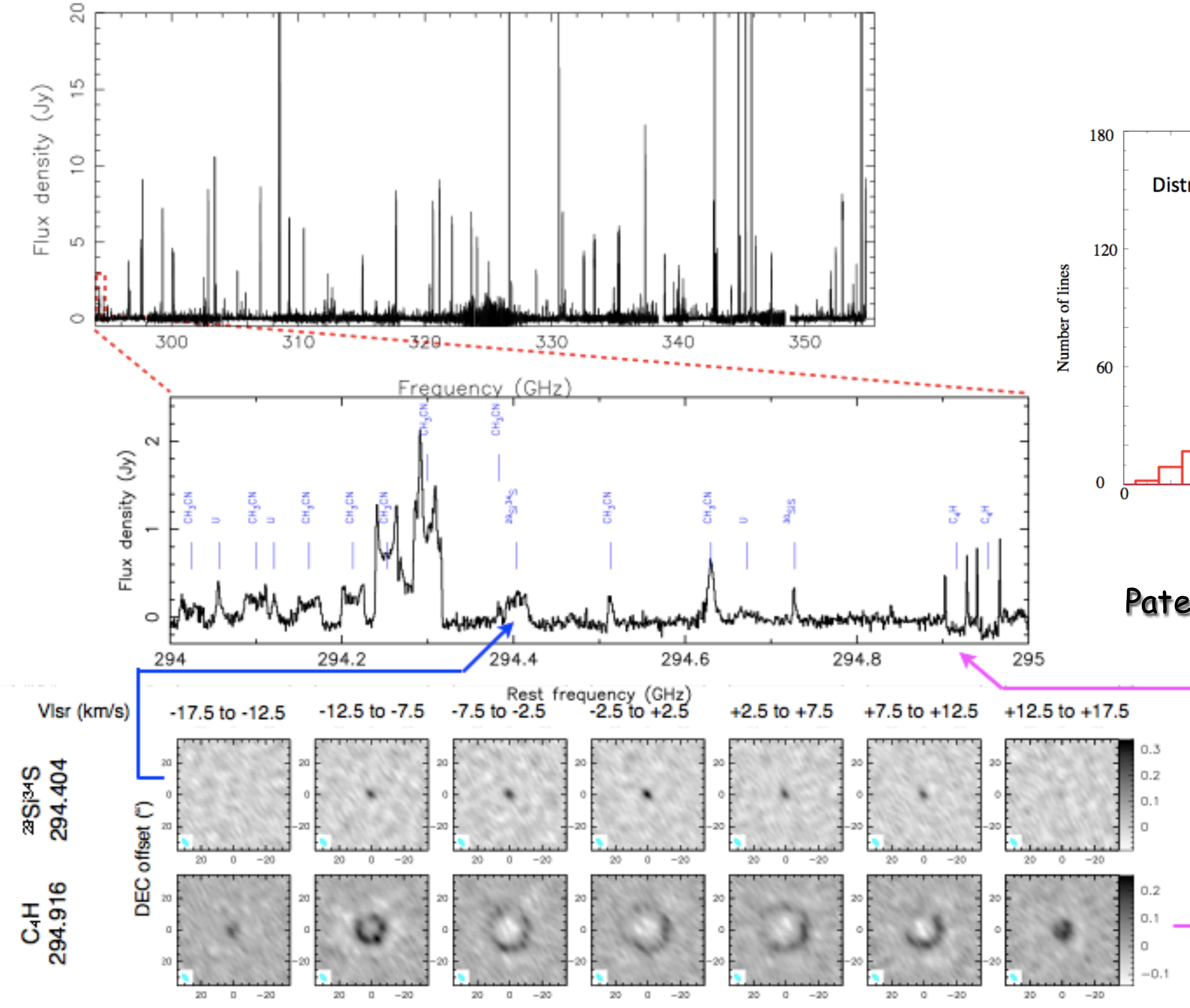
Chemical Evolution

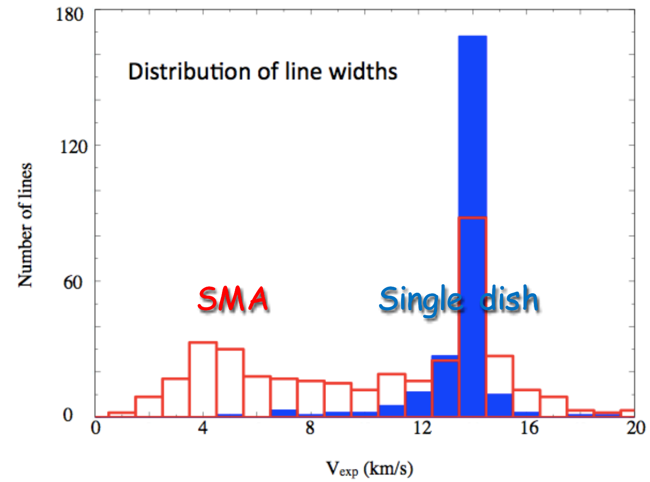


Wang et al. 2014

Increase of chemical complexity → Stellar heating evaporates complex organic molecules CH3OH, CH3CN, which then continue to evolve in gas phase reaction

IRC+10216 spectral line survey

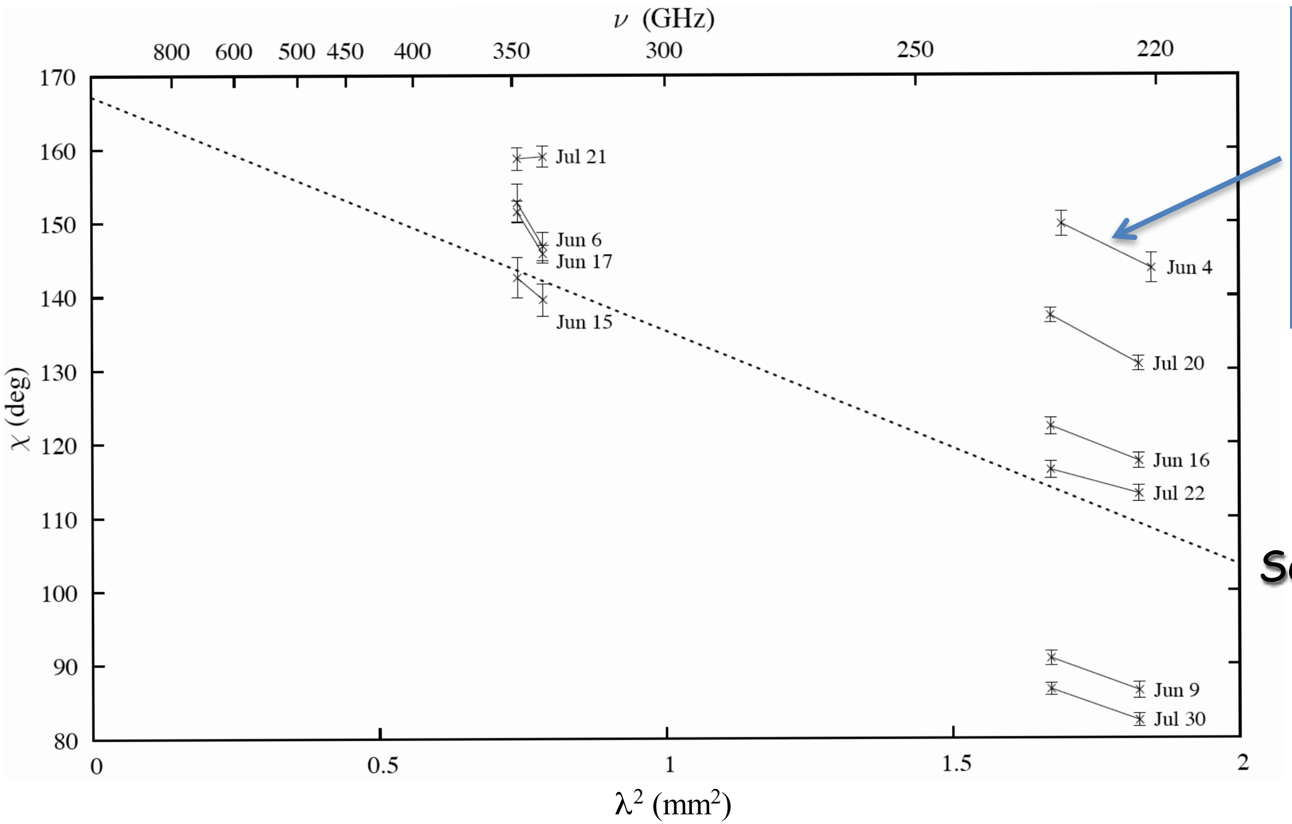




Patel et al. 2009, 2011

Faraday Rotation in Sgr A*

(Marrone et al. 2006)



$\chi = \chi_0 + \lambda^2 \, RM$

$RM = 8.1 \times 10^6 \int n_e B \cdot dl$

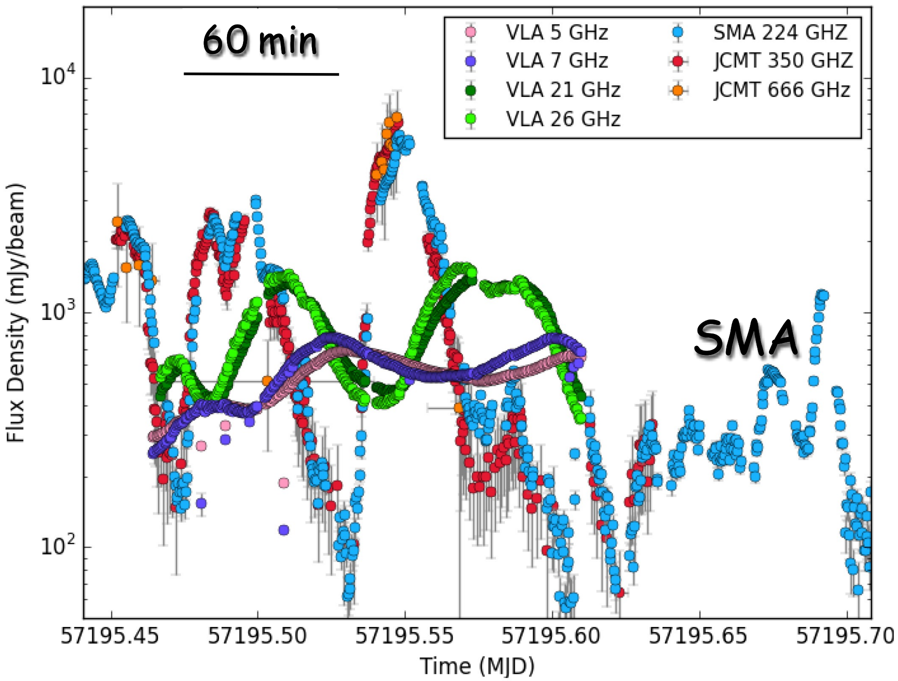
$= -5.1 \times 10^5$ rad/m²

Accretion rate ~ 10^{-8} M_{Sun}/yr

See also Kuo et al. 2014 on M87

Time Domain Astronomy: BHXB V404 Cygni

Light curve on June 22, 2015
Tetarenko et al. 2015



Closest known black hole X-ray binary at 2.39 kpc, 10 Msun, 6.5d orbital period

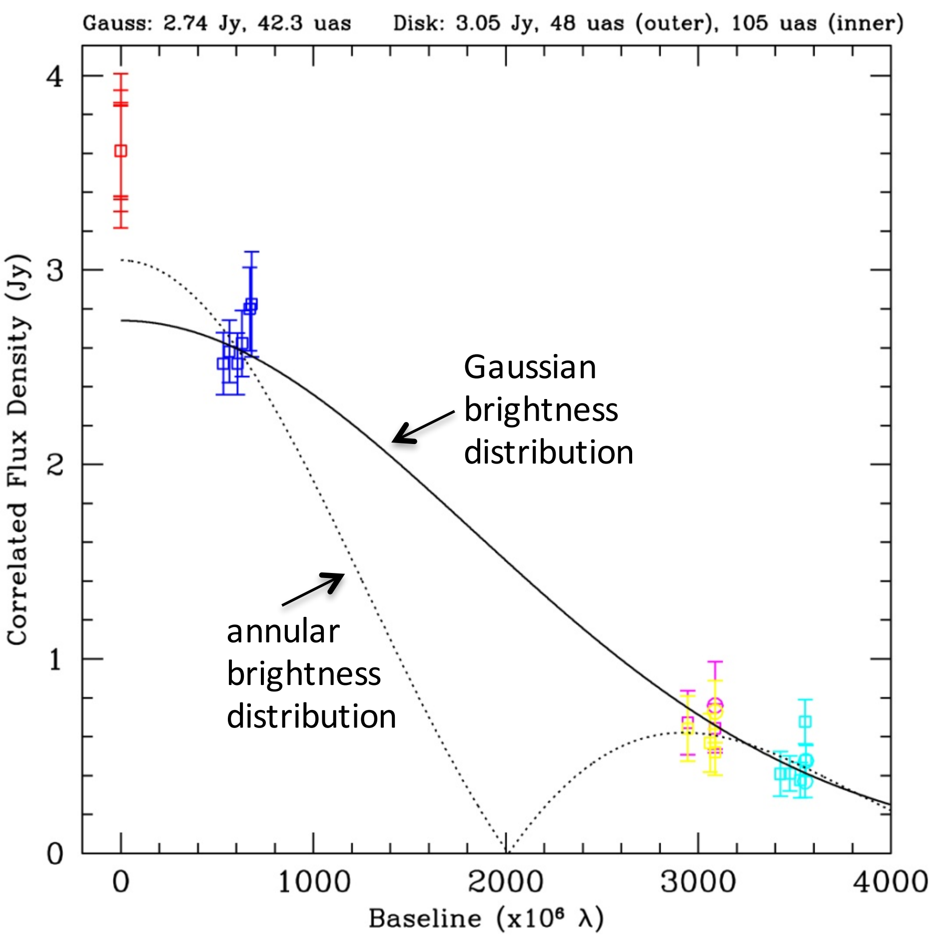
Being quiescent for 26 yrs, first time detection in mm/submm wavelengths

Time variability in mins to days, largest flare rose 75 mJy to 6 Jy in 25 mins

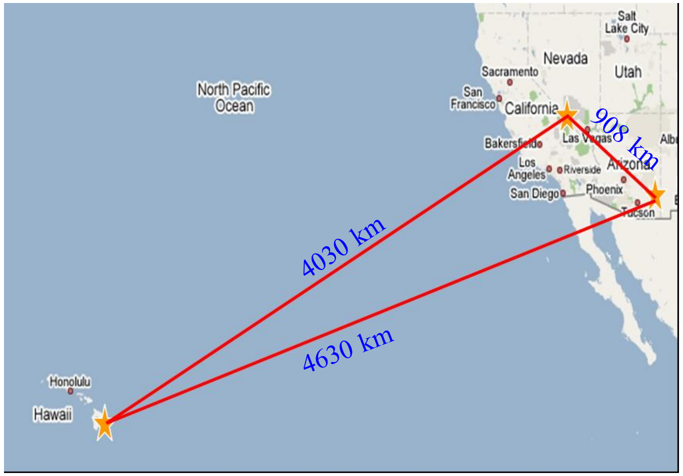
Mm/submm emission shows higher variability and lead cm emission, consistent with optically thin plasma ejecta in the jet.

GRB: time coverage before the peak of the light curve is critical
AGN: time monitoring

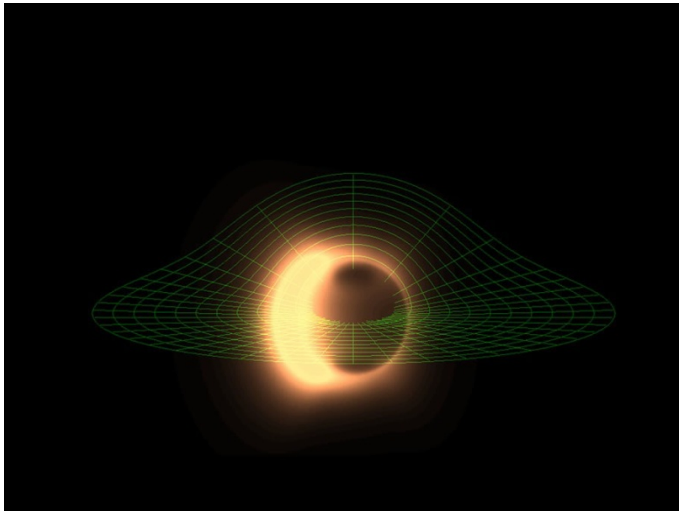
1.3mmλ VLBI Observations of SgrA*



Doeleman et al. 2008, also Johnson+ 2015
See also Doeleman et al. 2012 on M87



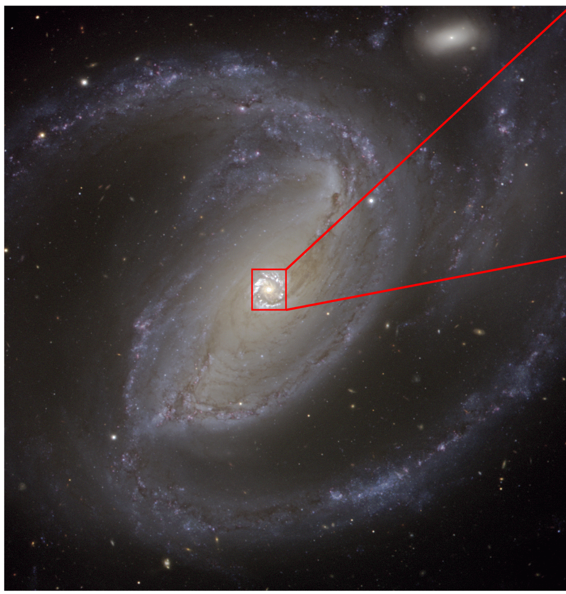
Baselines among Mauna Kea, CARMA, SMT



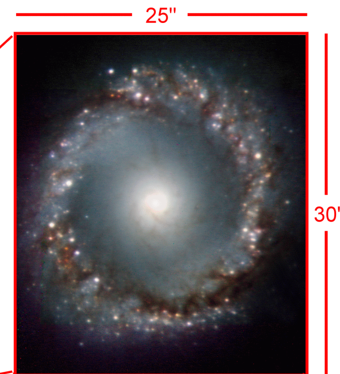
Simulation of orbiting "blob" close to inner-most stable circular orbit (Broderick & Loeb)

Seyfert Galaxy NGC1097

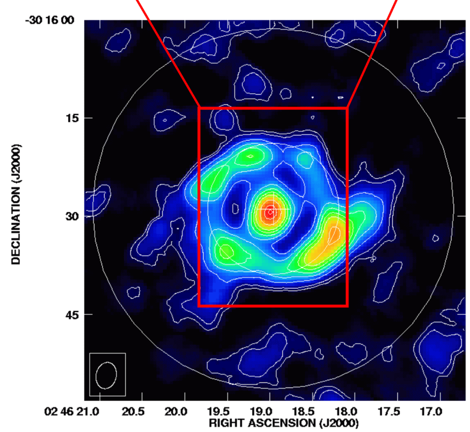
VLT Optical



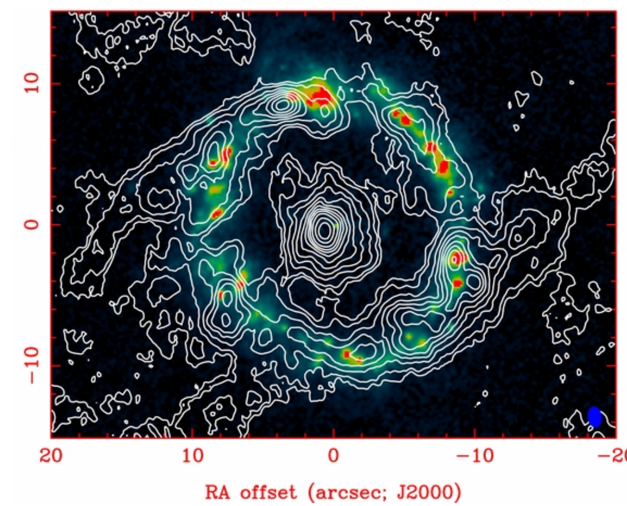
VLT Near-Infrared



SMA observations reveal molecular gas in a circumnuclear ring and in the nucleus of the galaxy that fuels the starburst.

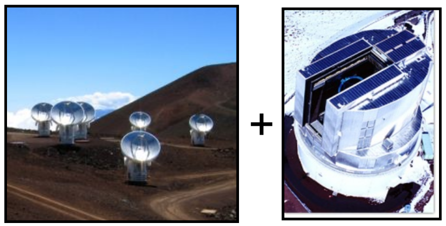


SMA $^{12}CO(J=2\text{-}1)$



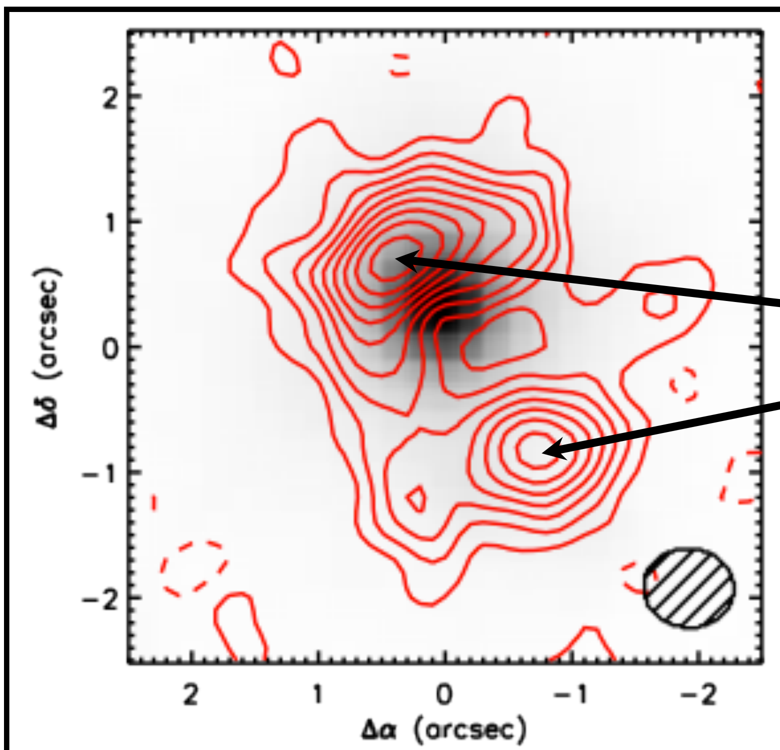
Hsieh et al. 2008, 2011

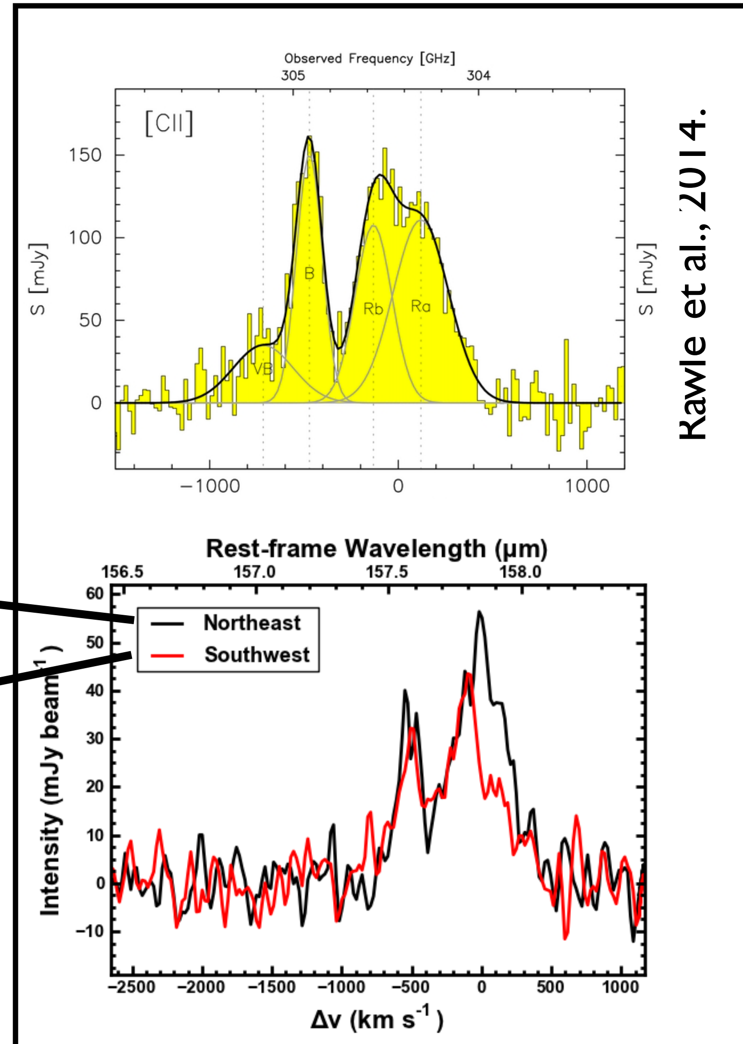
[CII] from an SMG at z=5.2



SMA + Subaru i-band

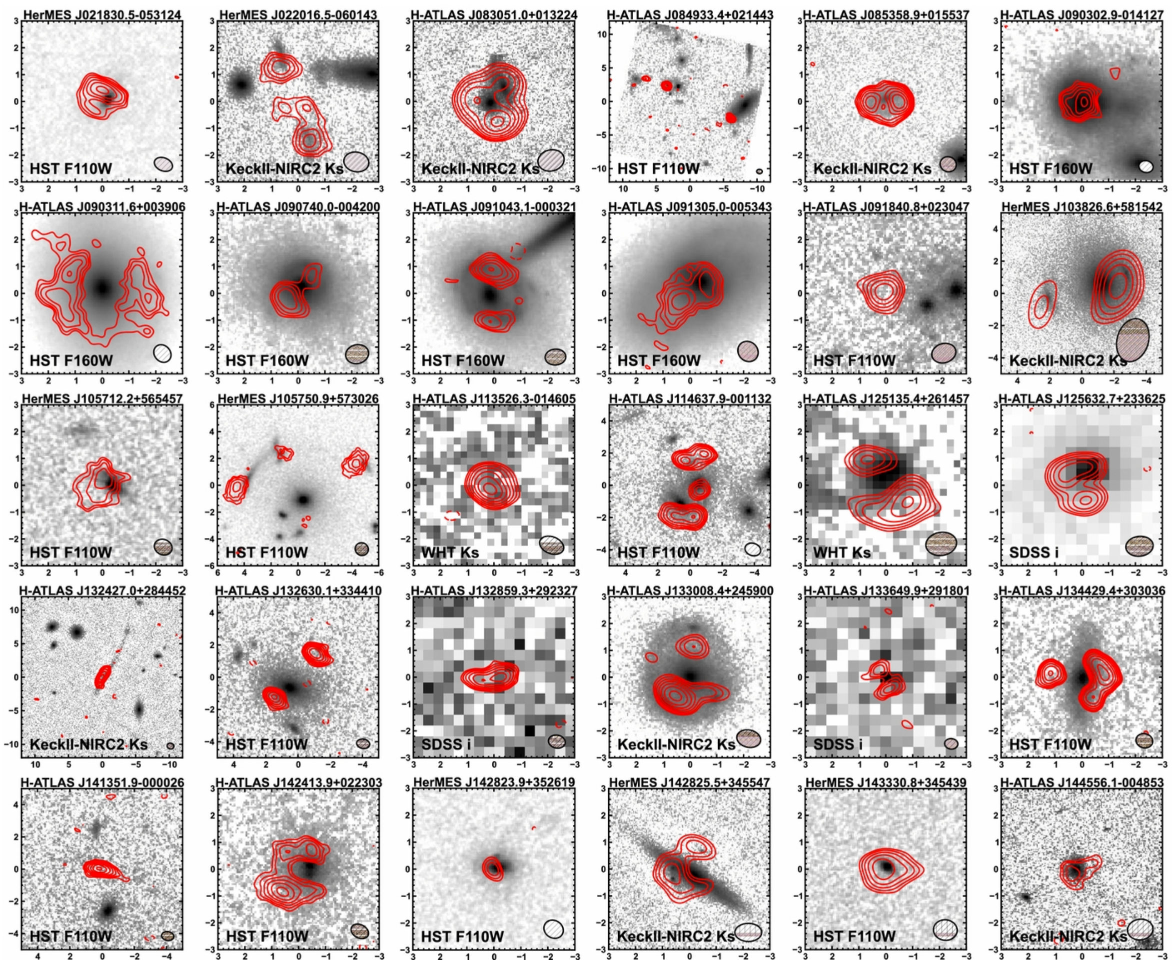
- z_{source} = 5.243
- z_{lens} = 0.6





Rawle et al., 2014.

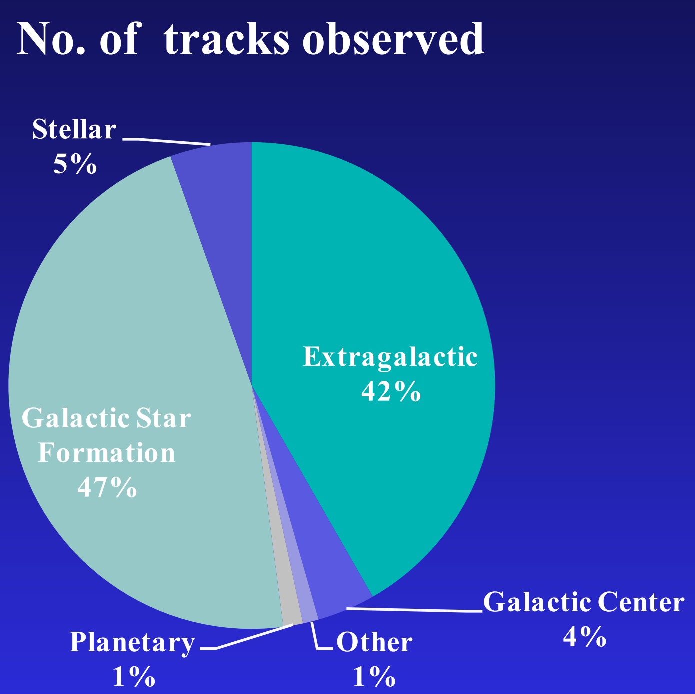
High-res SMA Imaging of 30 Lensed SMGs

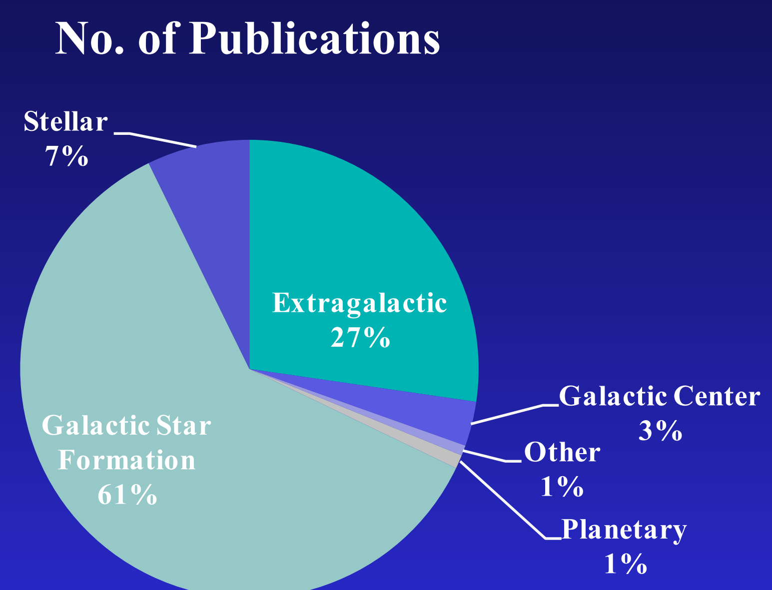


Bussmann et al., 2013

Observing time and publications

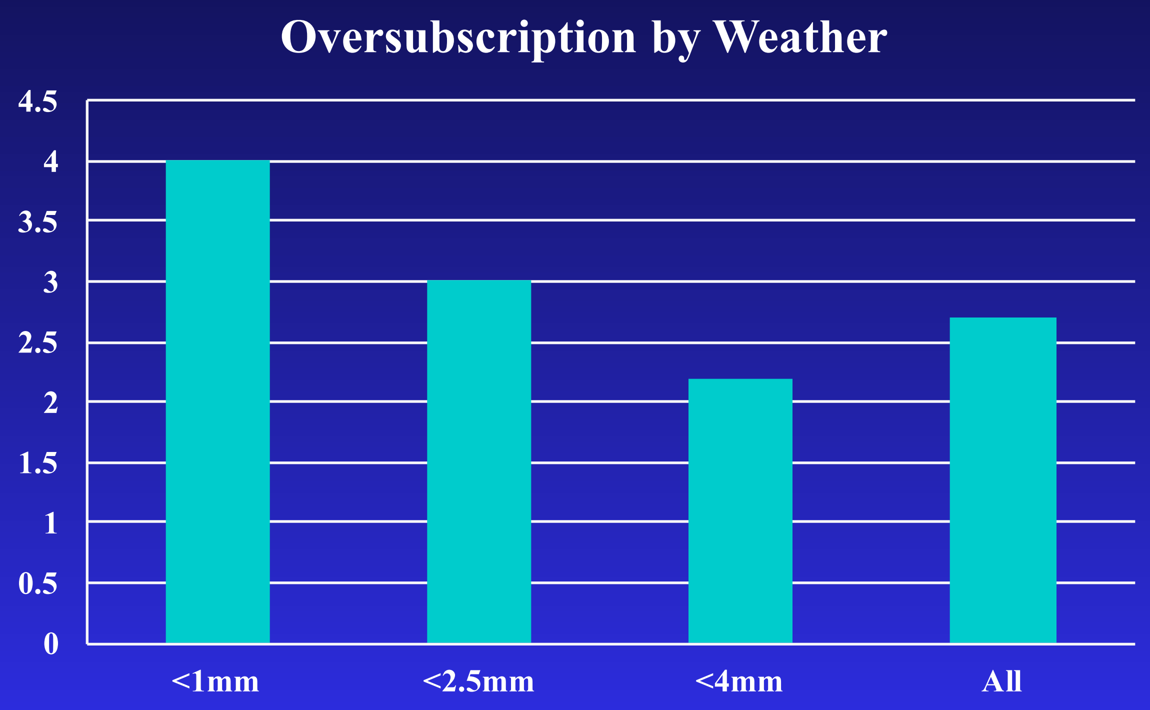
- Extragalactic projects tend to require more observing time as compared to star formation projects

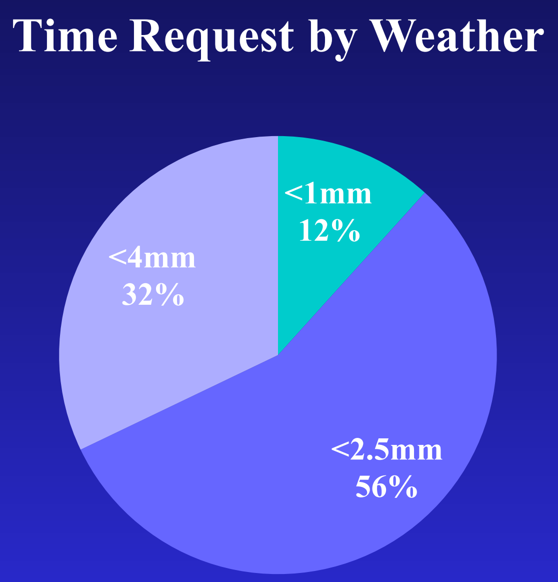




Time Oversubscription

- Majority of time requests come at PWV < 2.5mm, normally reserved for 345 GHz





Summary

- SMA is a highly sought instrument among the mm/submm community.
- Science output from the SMA remains steady, and compares favorably to other similar facilities.
- The main science output of the SMA is galactic star formation (61% publications) and extragalactic science (27% publications).